RHIC OPERATION IN 2001

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with contributions from many others

BROOKHAVEN NATIONAL LABORATORY

CBP Seminar, LBNL

6 December 2001

The RHIC accelerator complex

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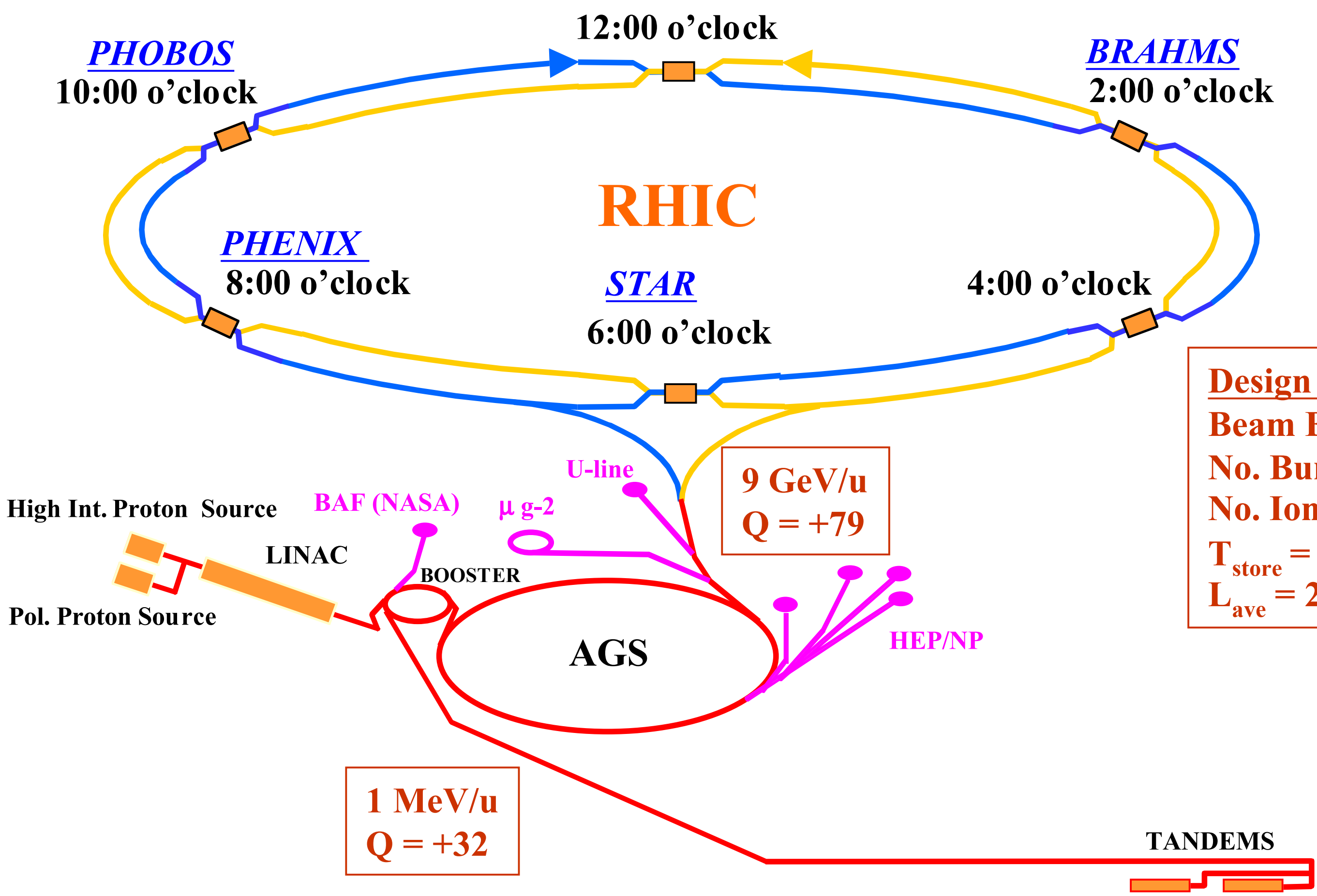


Design Parameters:
Beam Energy = 100 GeV/u
No. Bunches = 57
No. Ions /Bunch = 1×10^9
T_{store} = 10 hours
$L_{ave} = 2 \times 10^{26}\ \mathrm{cm}^{-2}\,\mathrm{sec}^{-1}$

Parameters for RHIC Au RUN 2001 (2000)

- 55(55) bunches per ring
- $1\times\ 10^9$ $(0.5\times\ 10^9)$ Au/bunch
  (100% at injection, up to 70% in operation)
- Longitudinal emittance: 0.5(0.5) eV•s/u
- Transverse emittance: 15(15) μm (norm, 95%)
- Storage energy: $\gamma = 107(70)$
- Storage bucket length: 5(36) ns
- Lattice in interaction regions:
  - $\beta^* =$ 10(3-10) m at injection
  - $\beta^* =$ 1-2(3) m at storage
- Instantaneous luminosity: $2\times\ 10^{26}(2\times\ 10^{25})\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$
- Integrated luminosity: 40-85 (3-6) μb^{-1}

RHIC pictures (1)

Injection arcs to
Blue and Yellow rings

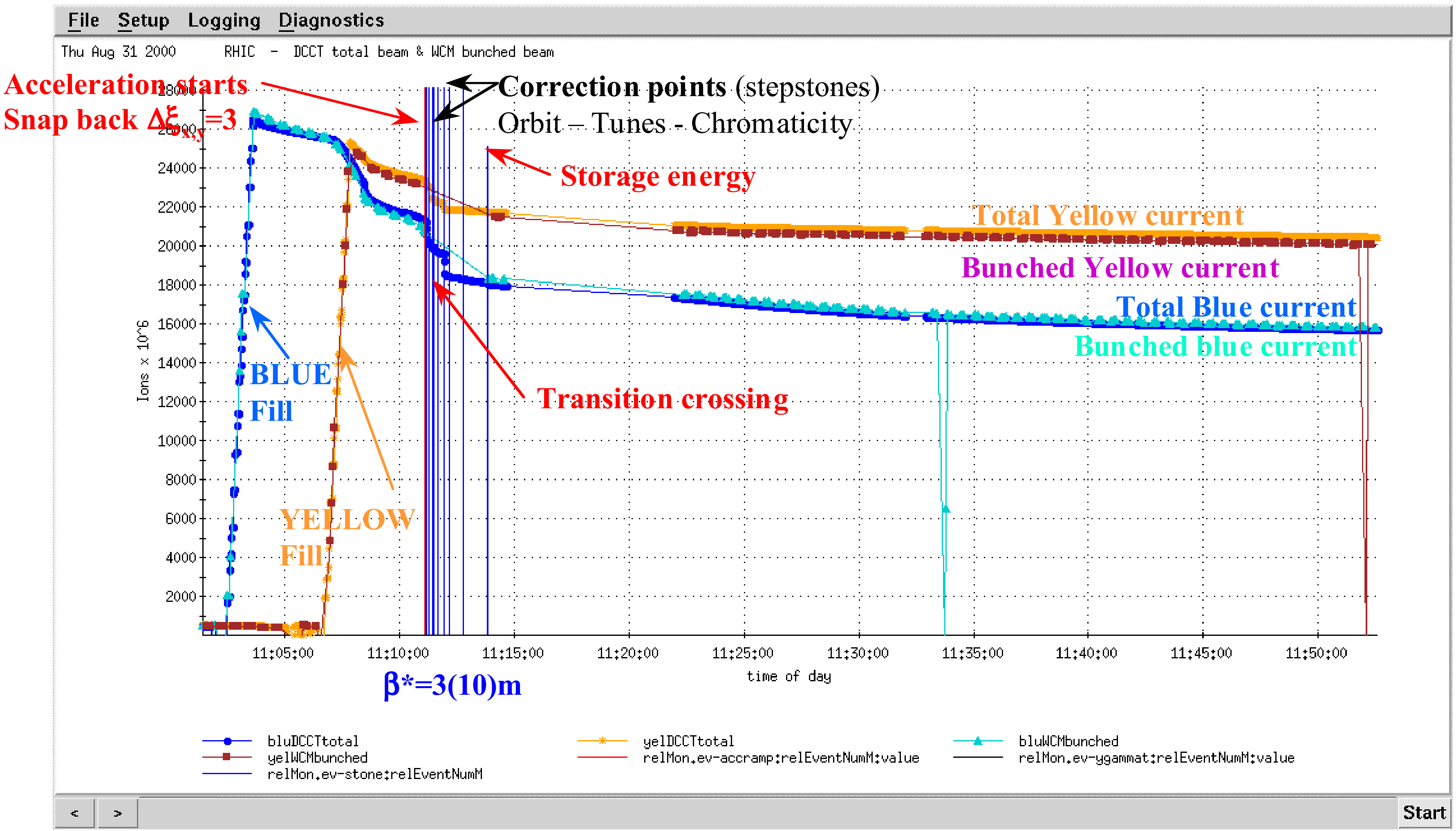
Blue and Yellow rings

RHIC pictures (2)

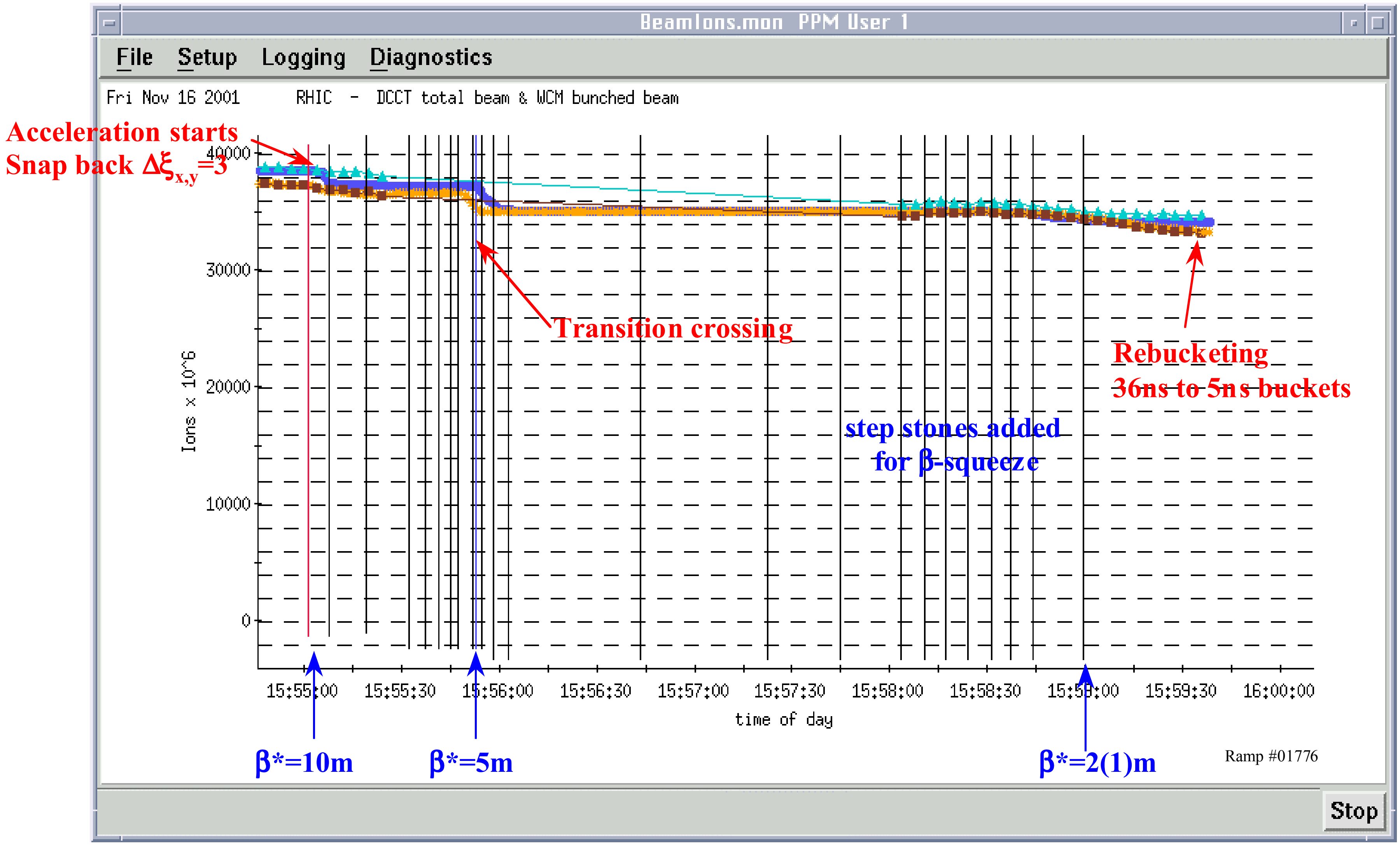
Installation of final focusing triplets

Rf storage cavities

RHIC ramp 2000

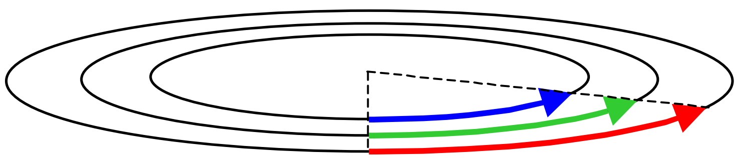


RHIC ramp 2001



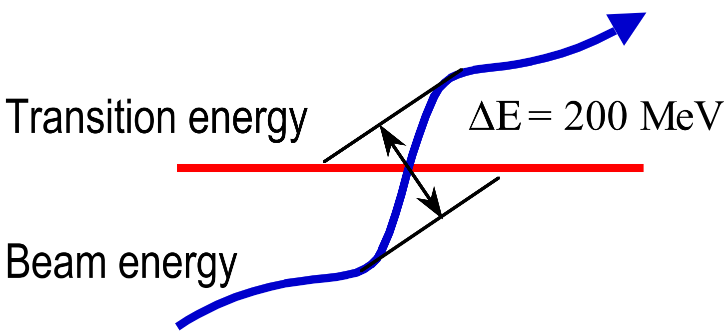
Transition crossing (1)

RHIC is first superconducting, slow ramping accelerator to cross transition energy:

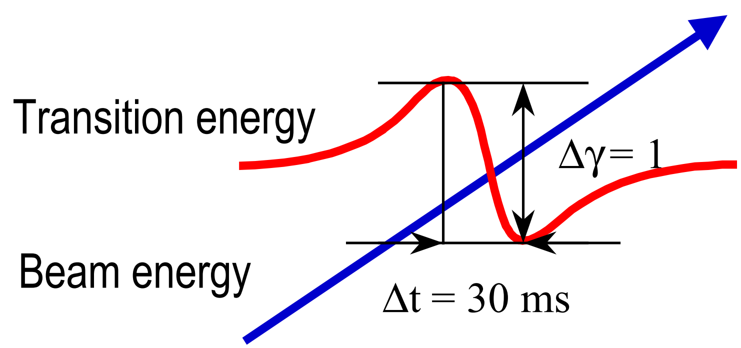


Slow and fast particles remain in step.
⇨ increased particle interaction (space charge)
⇨ short, unstable bunches

Cross unstable transition energy with radial energy jump (2000):



Cross unstable transition energy by rapidly changing transition energy (2001):

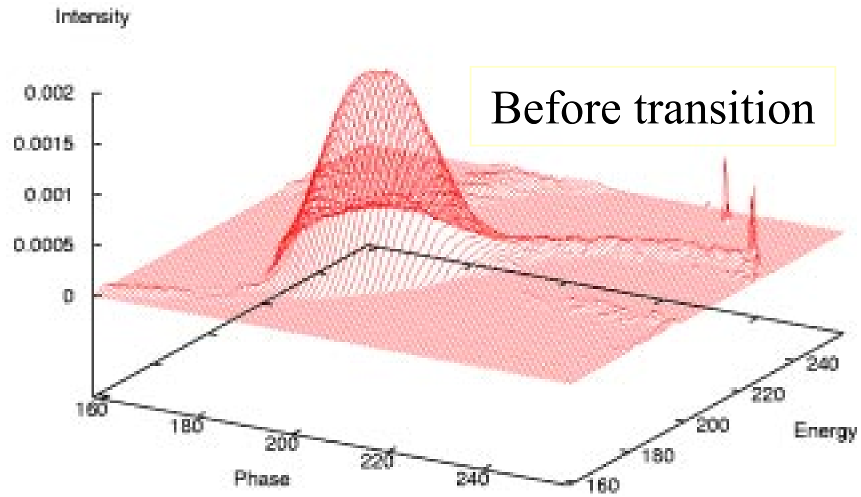


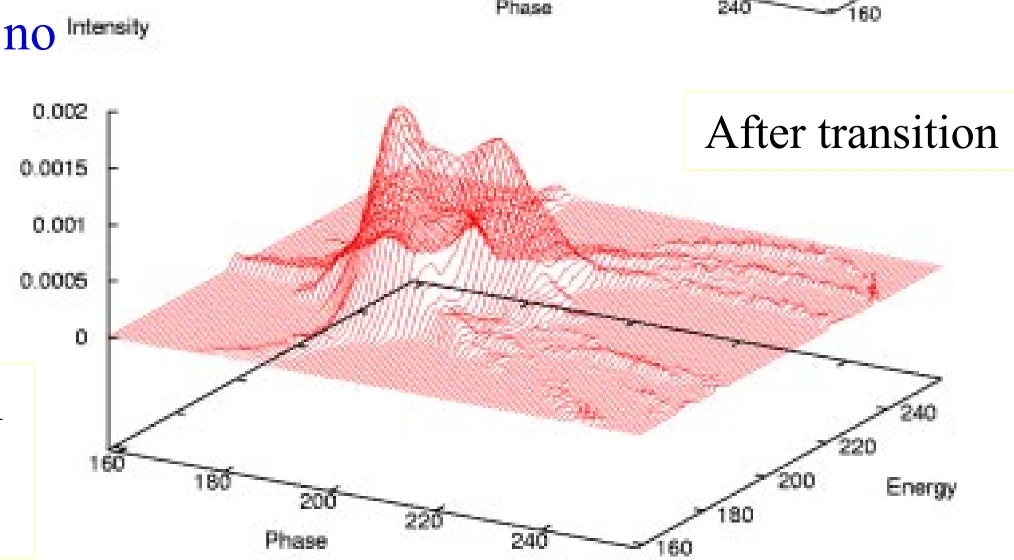
Avoids beam loss and longitudinal emittance blow-up

Transition crossing (2)

Transition effects:

1. Increase of longitudinal emittance
2. Fast transverse instability
   (10ms growth rate)
   => Need additional tune spread
      - from beam-beam
      - from octupoles
3. Head-tail instability since no Chromaticity jump

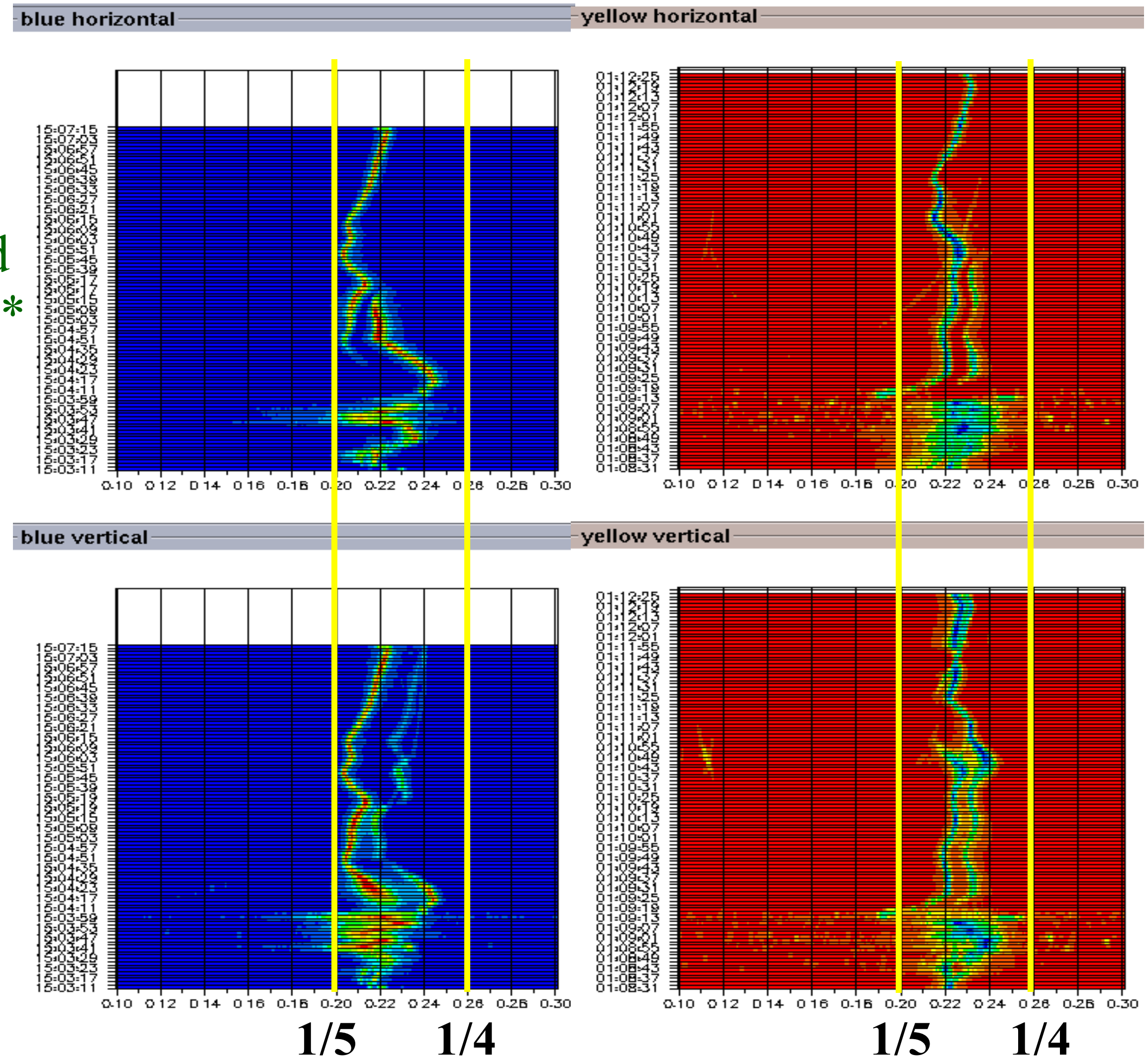




Tomographic reconstruction of longitudinal phase space (C. Montag)

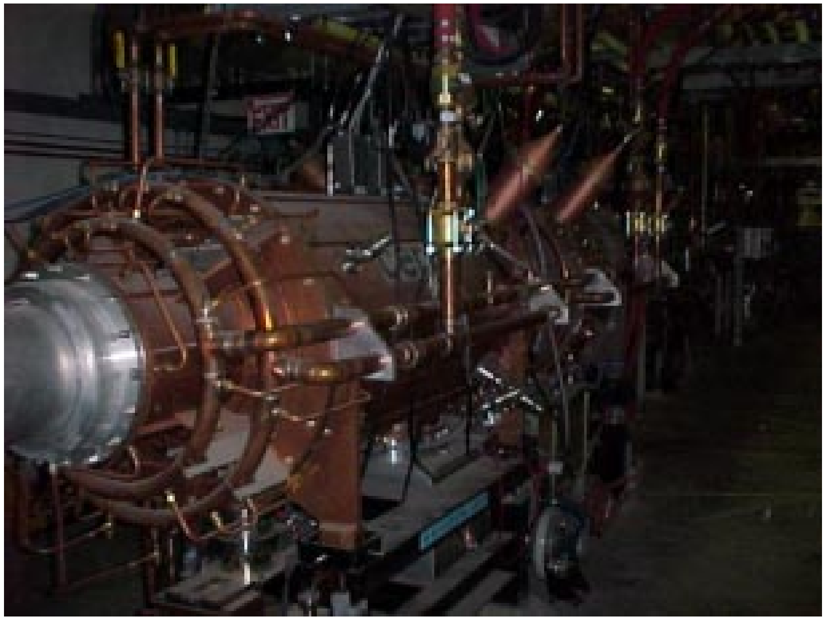
β-squeeze

- Tunes kept between 0.2 and 0.25 during ramp
- More step stones needed when going to smaller β*
- Orbits, tunes and chromaticity iteratively corrected in successive ramps



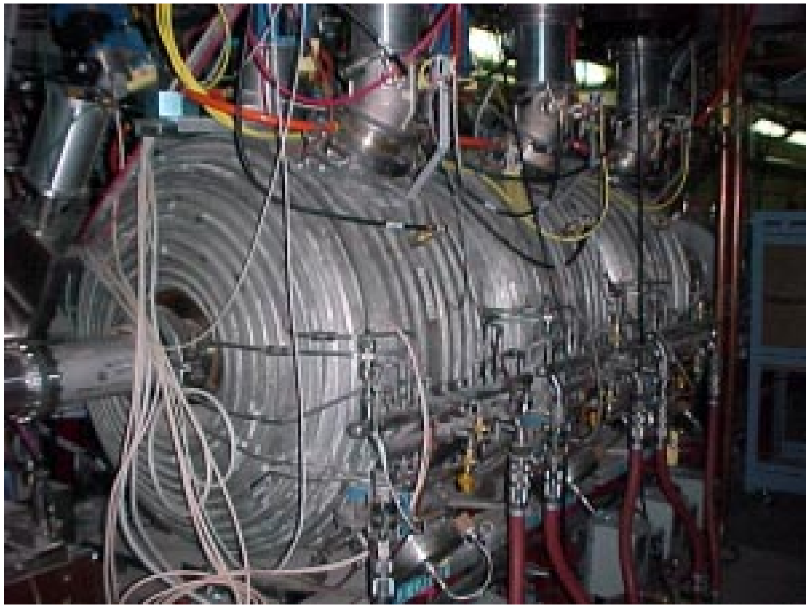
RF systems (1)

Accelerating system: 28 MHz



- Bucket length 36ns
- Large frequency range (125kHz)
- Mechanical tuner
- 2 Cavities, 150kV each

Storage system: 197 MHz



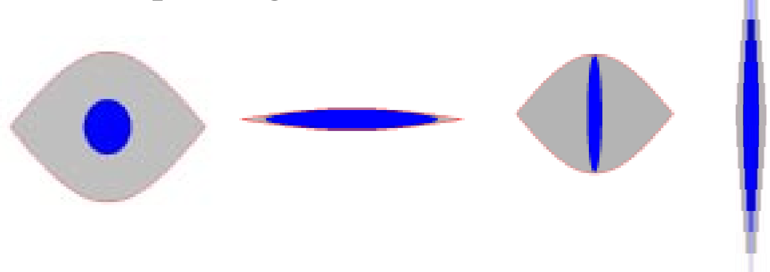
- Bucket length 5ns
- 3 Cavities in Blue and Yellow each
- 4 Common cavities
- Up to 1MV per cavity

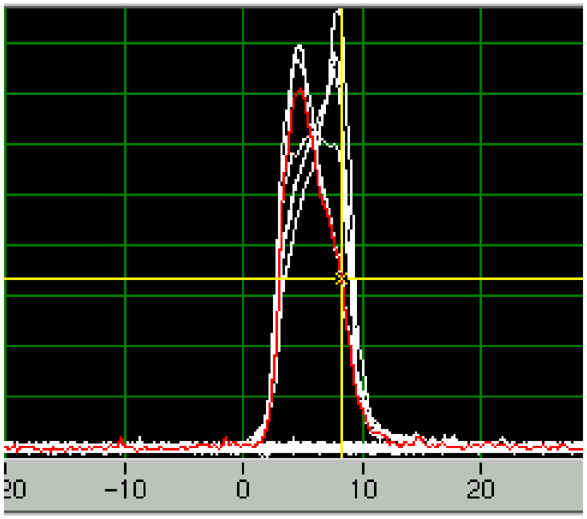
RF systems (2)

Blue before rebucketing

- sustained longitudinal oscillations at high intensities (no emittance growth)
- cured with “Landau cavity”

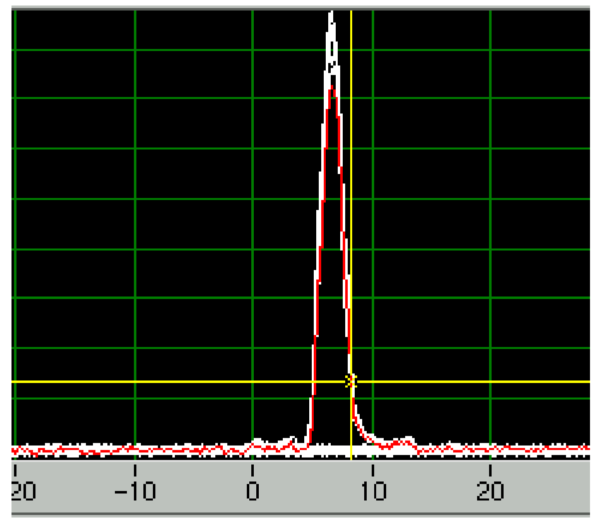
Counter-phasing the 2 acceleration cavities



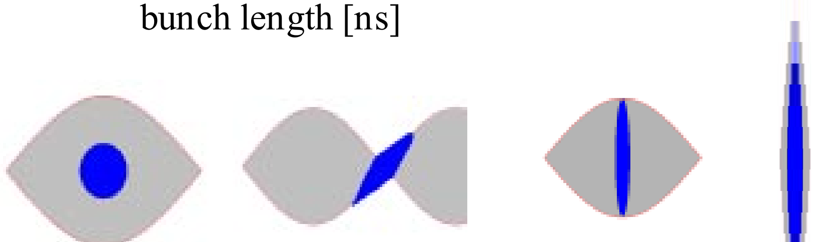


bunch length [ns]

Blue after rebucketing

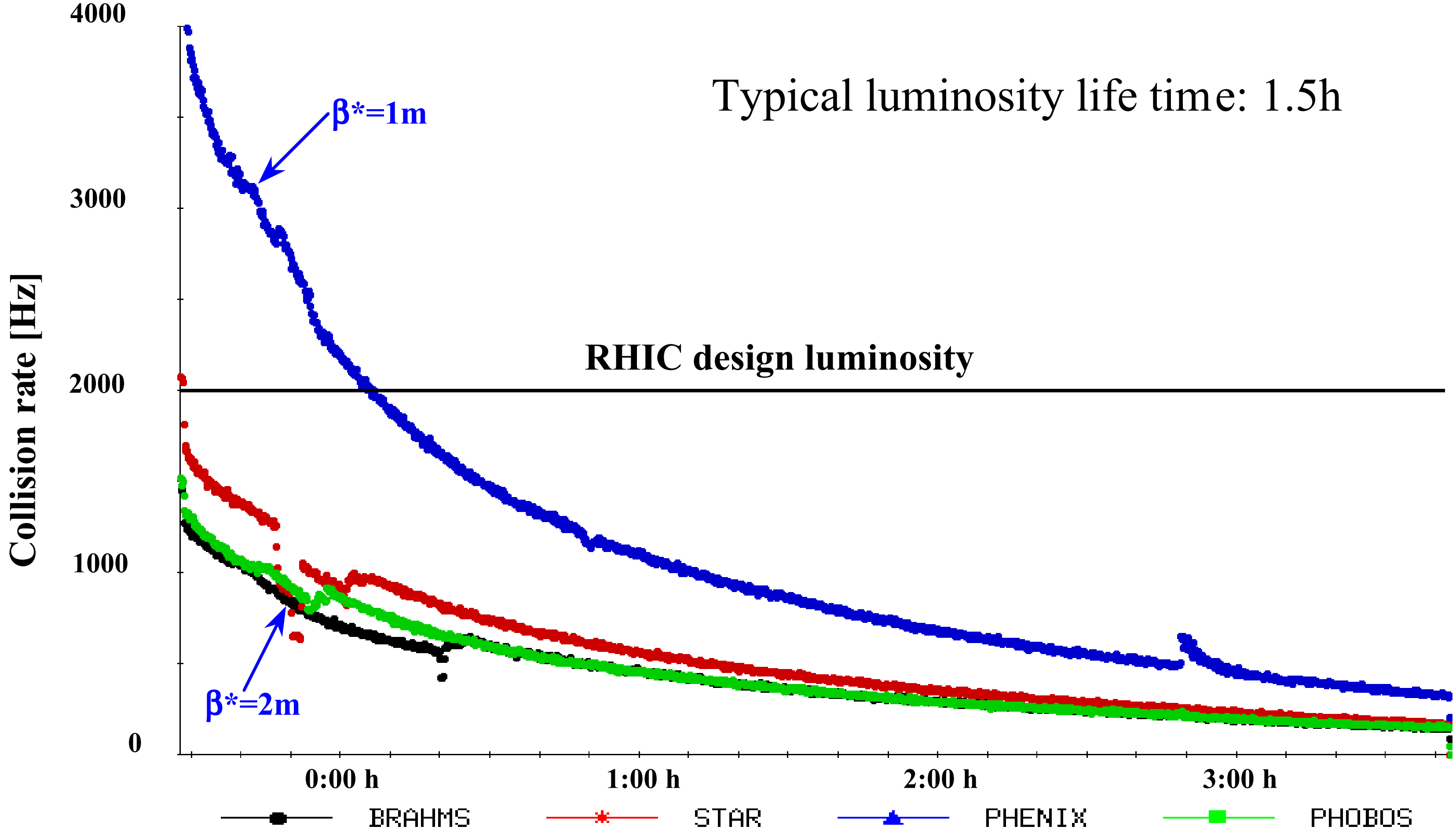


bunch length [ns]

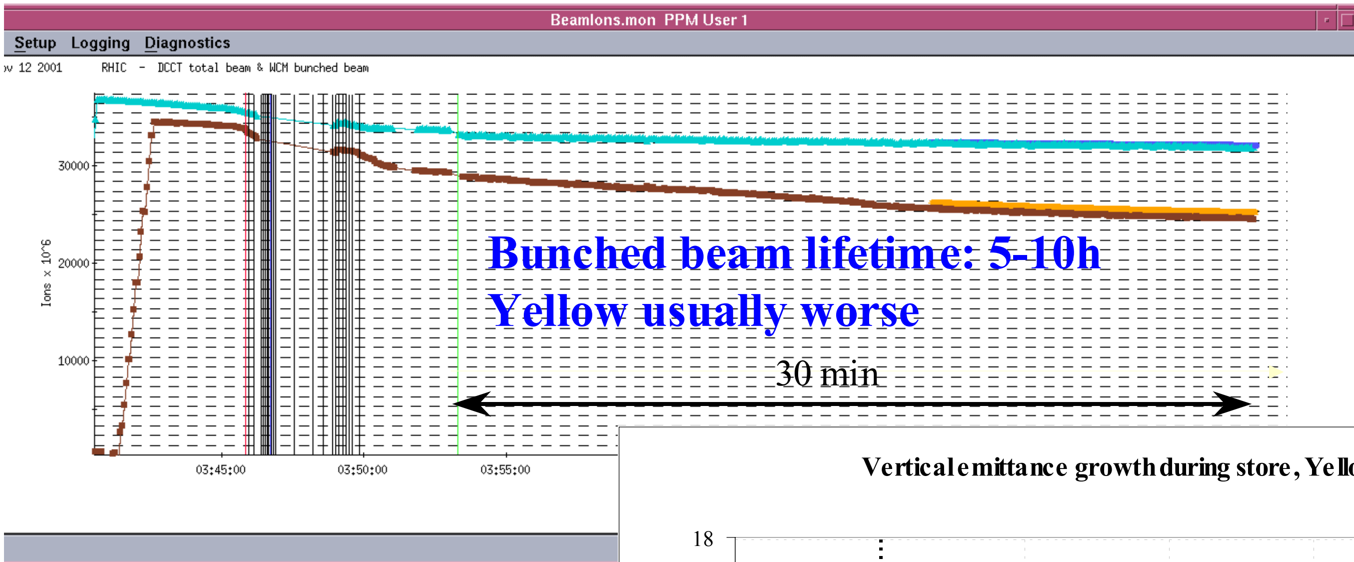


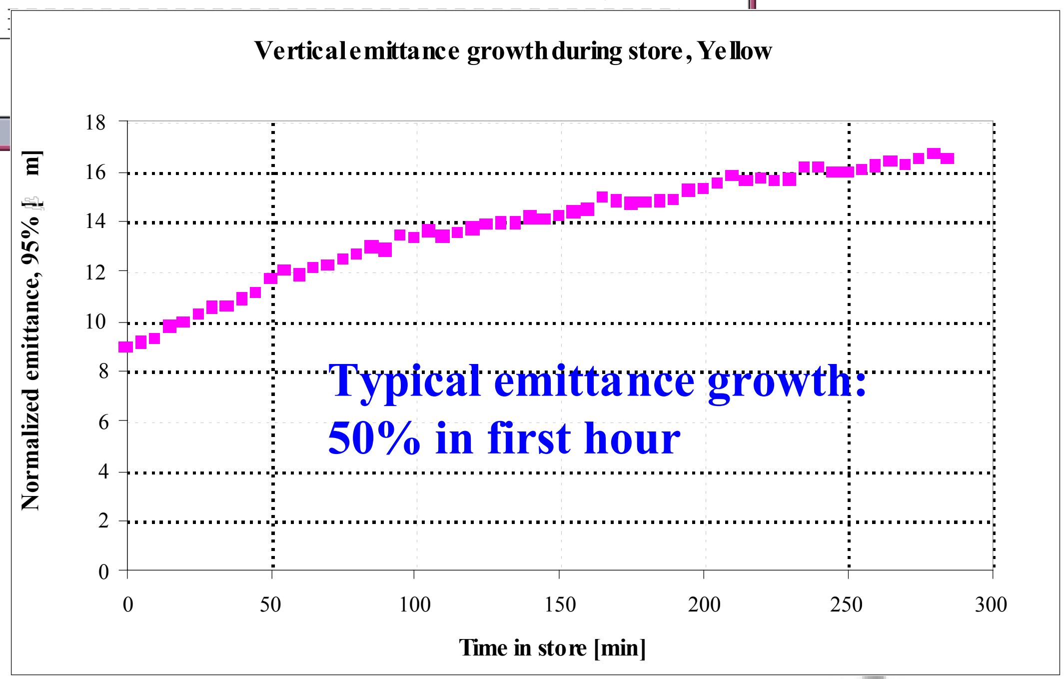
Phase jump to unstable fixed point and back

Luminosity lifetime (1)



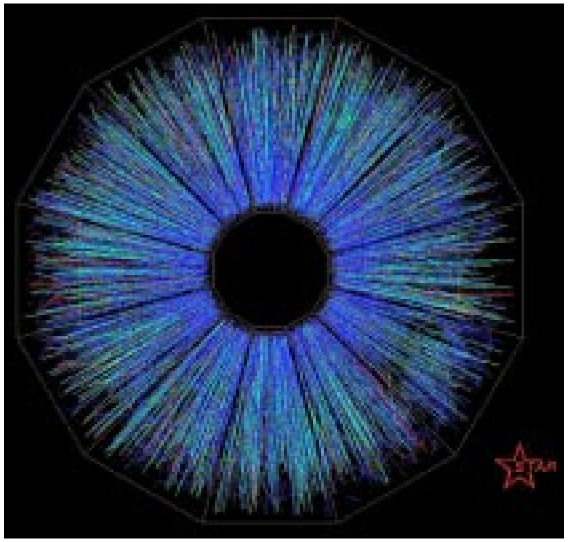
Luminosity lifetime (2)



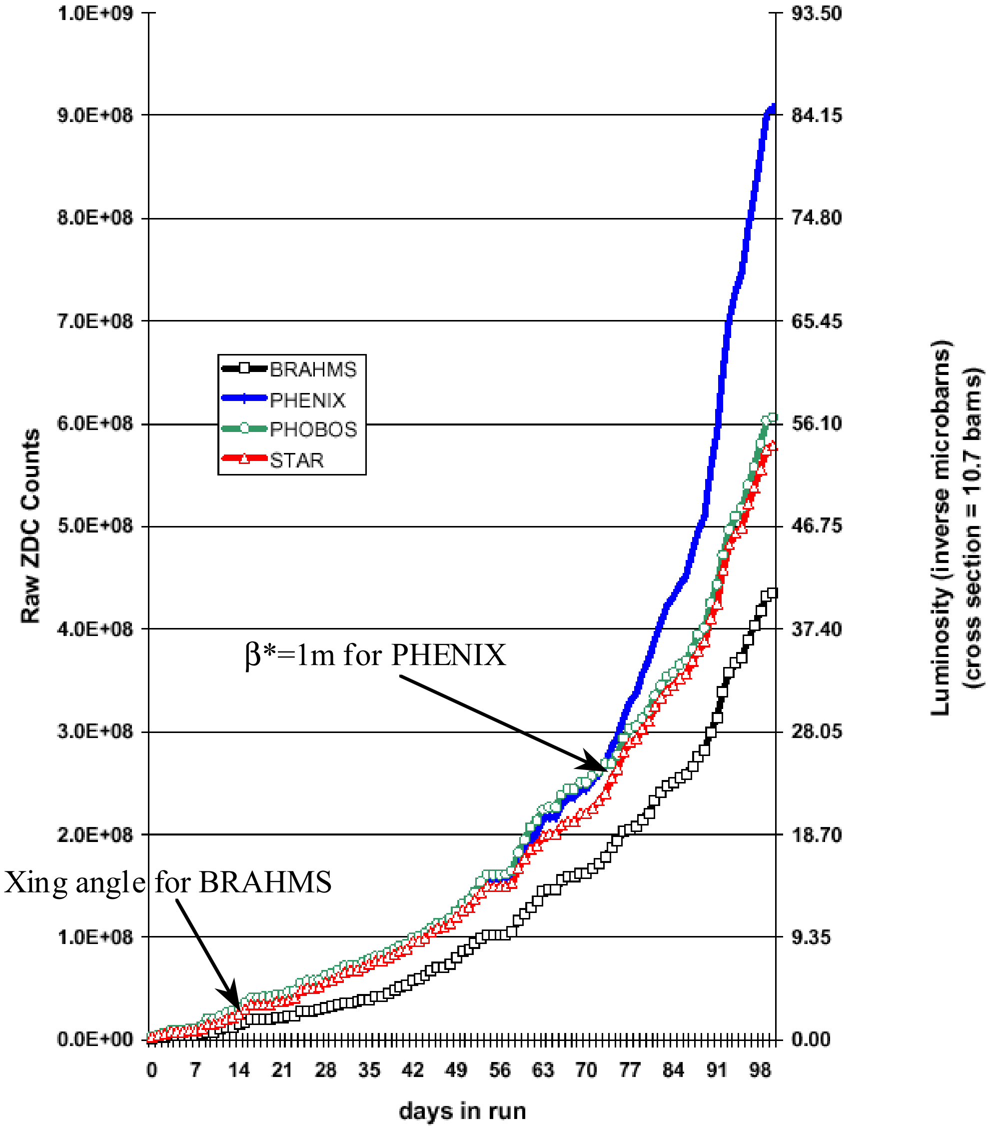


Sources for lifetime reduction and emittance growth:
- less physical aperture in Q2
- external modulations
- IR field errors
- beam-beam
- IBS

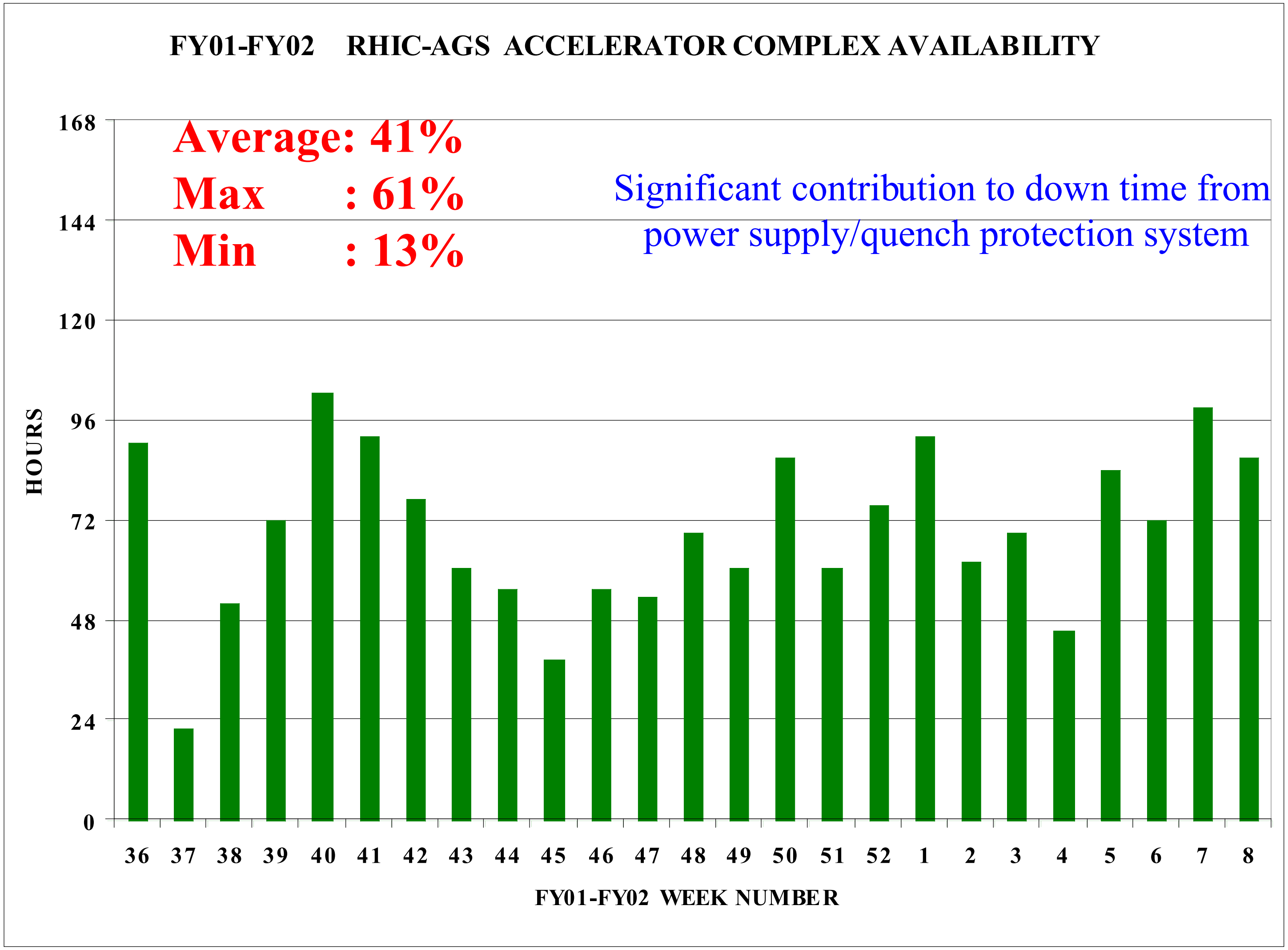
RUN 2001 integrated Au-Au luminosity



Au-Au collision seen by STAR

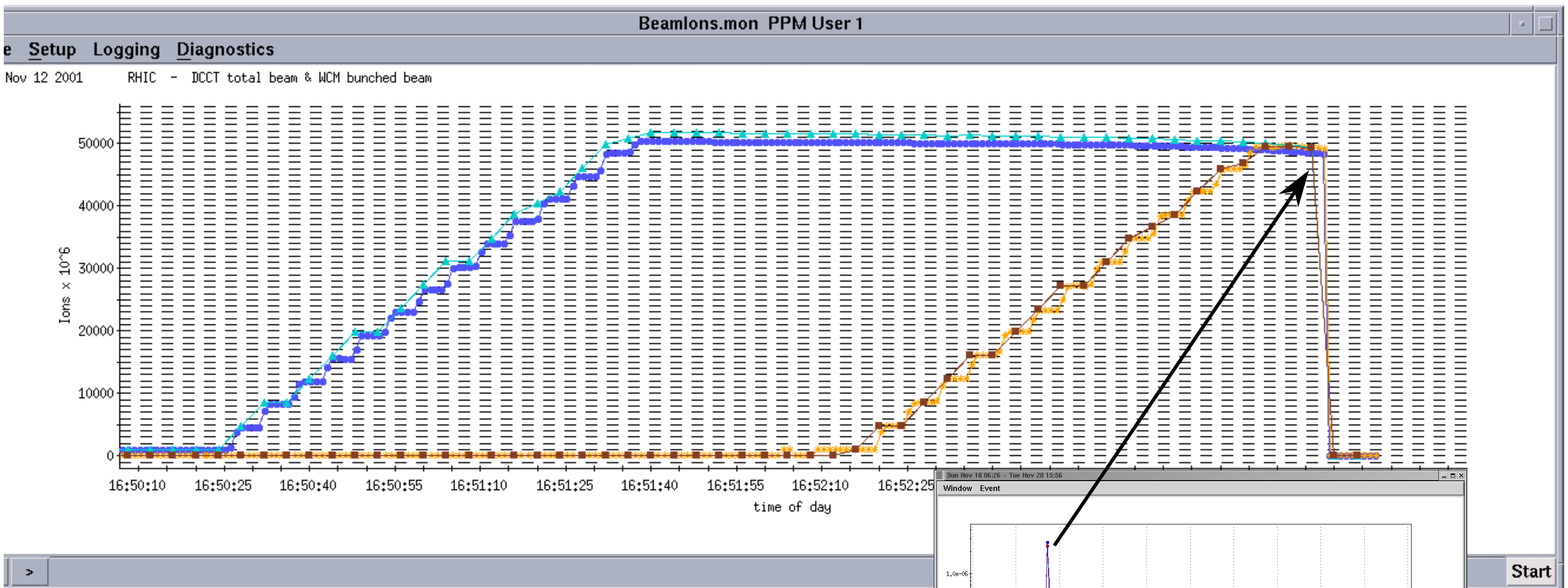


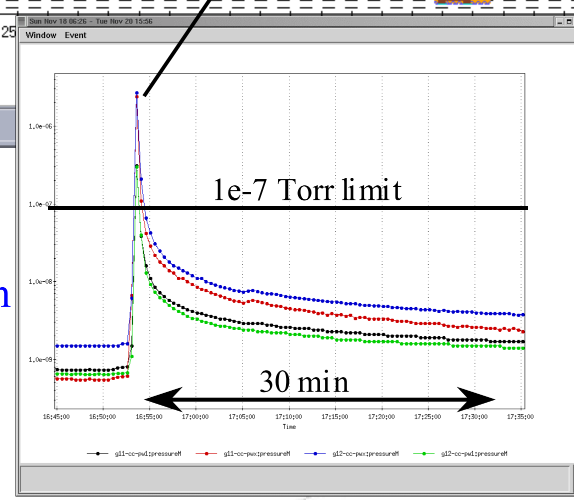
Limitations – machine availability



Limitations – vacuum failure (1)

- 55 bunches in each ring
- design intensity (1e9 Au ions/bunch)
- 216ns bunch spacing





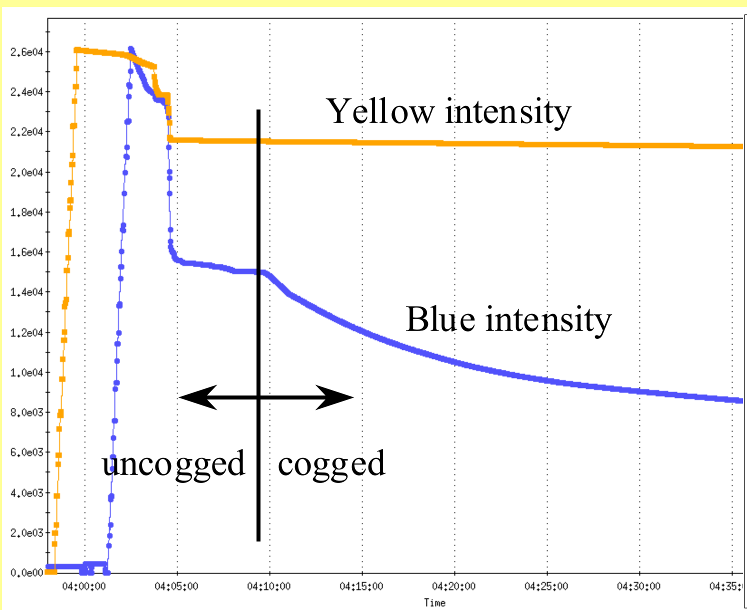
Rising vacuum in a warm region pulls permit link

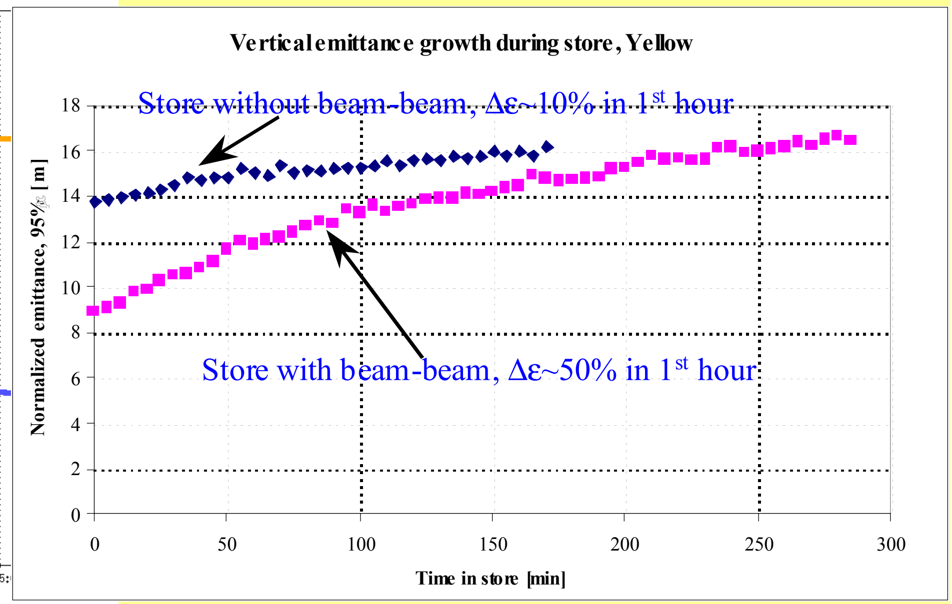
Limitations – vacuum failure (2)

- Always in warm (field free) regions
- Faster with higher intensity and shorter bunch spacing (216ns $\rightarrow$ 108ns)
- Faster with two beams (effective short spacing in common regions)
- Typically with loss producing situations (injection, transition, orbit problems)
- Experimental solenoid magnet (~0.5T) ameliorates pressure rise
- Gaps of 1μs do not reset pressure rise

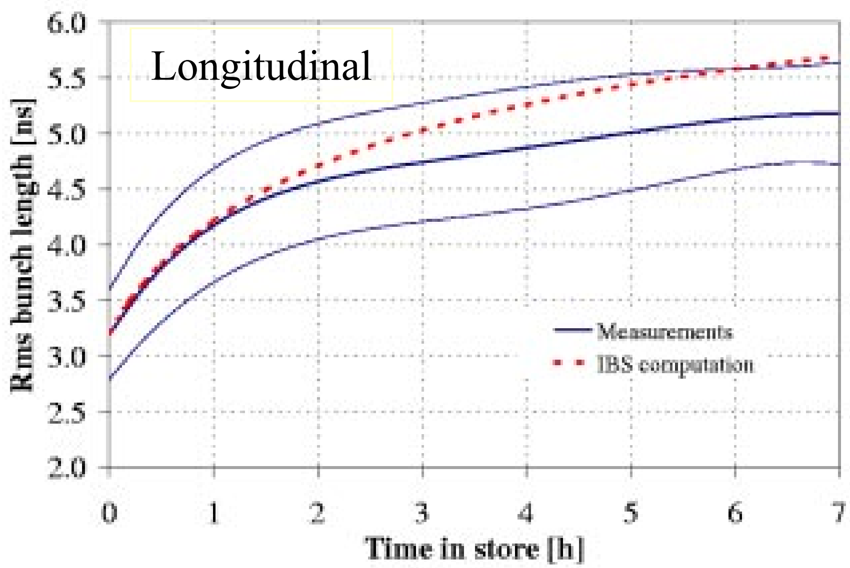
Limitations – beam-beam

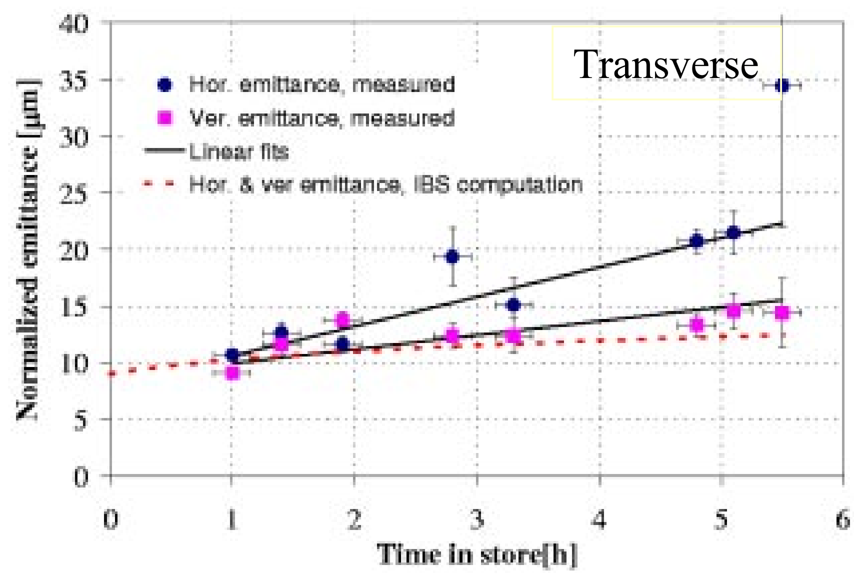
- $\xi_{tot,max}$ up to 0.005 in 2001
- Tune modulation with ξ_{tot} during ramp
  (unequal radio frequencies in the two rings)
- Lifetime deterioration and emittance growth at store
- Only existing strong-strong hadron collider,
  => possibly coherent modes





Limitations - IBS





Longitudinal emittance growth agrees well with model
Additional sources of transverse emittance growth like
- booster cycle (5 seconds)
- 10 Hz orbit modulation (~0.03σ at IPs) from triplet vibrations

IBS will determine RHIC Au performance

Beam studies program (12h/week)

- Optics
- Electron clouds
- Local nonlinear IR correction
- Beam-beam
- Intra-beam scattering
- Longitudinal impedance (Q_s vs. intensity)
- Transverse impedance ($Q_{x,y}$ vs. intensity)

RHIC upgrade possibilities

- Luminosity upgrades can be achieved by
  - Decreasing β^* further with modified optics
  - Increasing bunch intensity
  - Increasing (decreasing) bunch number
  - Decreasing beam emittance
- All options are limited by intra-beam scattering => beam cooling at full energy
- Preliminary study on RHIC electron cooling shows that luminosity can be increased ten times.
- Energy upgrade to 120 x 120 GeV/u (Au) possible by replacing the DX magnets.

Summary RHIC RUN 2001

- RHIC’s 2nd year of operation achievments:
  - design energy
  - short bunches in store
  - design Au luminosity
- Limitation to higher Au luminosity (in likely order of appearance):
  - machine availability
  - vacuum failure at high intensity (e-clouds)
  - magnetic field errors in IRs
  - collective instabilities
  - intra-beam scattering
  - beam-beam effects
- Polarized proton run is under way

Electron Cooling at RHIC Storage Energy

- Electron beam cooling at full RHIC energy could eliminate IBS limitation and even reduce beam emittance further.
- Feasibility supported by study produced by BINP (V. Parkhomchuk et al.)
- Bunched electron beam requirements for 100 GeV/u gold beams: E = 54 MeV, $\langle I \rangle \leq 100$ mA, electron beam power: ≤ 5 MW
- Requires high brightness, high power, energy recovering superconducting linac, almost identical to IR FEL at TJNAF
- Has several applications at BNL: PERL, eRHIC (EIC)
- First linac based, bunched electron beam cooling system used at a collider
- First high p_t electron cooler to avoid recombination of e^- and Au^{79+}